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Meteorological Survey of Mars

For Opposition Years 1965 - 1995

By: JEFFREY D. BEISH

Association of Lunar and Planetary Observers (A.L.P.O.)

INTRODUCTION

Starting with the 1964-65 Apparition of Mars, the International Mars Patrol (I.M.P.) began a systematic observing program designed to record all meteorological activity on Mars using pre-selected colored filter observing techniques developed by the well known Mars authority Charles F. (Chick) Capen, Senior A. Mars Recorder. A continuation of the systematic ground-based support for Mars studies represents the International Mars Patrol. The I.M.P. coordinated the efforts of 1,074 astronomers located in the United States and foreign countries interested in detailed study of the planet Mars organized for a 24-hour surveillance program of the planet during each apparition. The I.M.P. is the primary observing program for the Mars Section of the Association of Lunar and Planetary Observers (A.L.P.O.).

The I.M.P. archives contain 26,161 observations of Mars to date. A catalog of 24,130 observations of Mars has been used for this survey. This paper presents statistical analyses from the wealth of data obtained during the 31-year period from 1964 through 1995 for investigating seasonal and long-term patterns in the meteorology and climate.

Part-I of the Meteorology of Mars report series briefly described methods used in the analysis and preliminary results of the 1981-82 Martian Environmental and Climatic Survey, [Beish *et al*, 1986]. Information pertaining to part one was obtained from observations of the Institute for Planetary Research Observers (I.P.R.O.). Further analysis using data from the Association of Lunar and Planetary Observers (A.L.P.O.) Section observation records were presented in Meteorology of Mars Parts-II, [Beish *et al*, 1987], and Part III [Beish *et al*, 1987].

A complete systematic survey of I.M.P. observations of Mars resulted in publication of a more detailed analysis of bright aerosols and condensates reported by A.L.P.O./I.M.P. observers during 1968 through 1985 and was presented to the American Geophysical Union [Beish and Parker, 1990].

MARTIAN CLOUDS, HAZES, AND WHITE AREAS

Clouds, hazes, and white surface areas are observed on Mars during every Martian season. Observational records indicate that these bright features exhibit certain characteristics similar to the familiar terrestrial clouds, fog's and hazes. They are especially bright in blue light and are sometimes observed to have bright colors. From these observations and from the data gathered by the Mariner spacecraft and the Mars Landers/Orbiters, we now know that H₂O ice clouds and CO₂ hazes do exist on Mars. We should be comfortable with the idea that what we observe as bright patches from Earth are clouds and hazes on Mars. Our Earth-based telescopic observations are more significant with this new knowledge [Capen, 1982].

Martian clouds, fogs, frost, and dust clouds come in various shapes and sizes and are sometimes observed to move around on the planet blocking out portions of the surface. We were particularly interested in their locations and movements, and their seasonal counts. Various methods have been employed to enhance the visibility of bright areas, one of which is the use of colored transmission filters. These filters are regularly used by

observers for visual and photographic observations of Mars and other planets [*Capen*, 1982].

Table 1 and Figure 1 are general histograms of the observational coverage during each Mars apparition this study. Figure 2 plots the number of visual, photographic, micrometric, and CCD images observed contributed during each opposition year.

Table I. History of ALPO/IMP observations from 1965 through 1993. Given are the dates from the first to last observation date and Planetocentric of the Sun (Ls), Ls range, total span of Ls from first to last observation, actual number observed, number of observers (OBS), and total observations (Visual, Photographic, Micrometer, and CCD).

Observation Dates	Opposition (Ls)	Ls Range(Span)	Ls Observed	Obs	T
1964 Sep 11-1965 Aug 25	1965 Mar 09 (84)	3-165 (163)	100	3	
1968 Nov 22-1970 Mar 12	1969 May 31 (165)	75-336 (262)	120	31	
1970 Nov 29-1972 Feb 18	1971 Aug 10 (232)	97-347 (251)	138	115	
1973 Feb 24-1974 May 19	1973 Oct 25 (306)	160- 50 (251)	163	78	
1975 Mar 18-1976 Jul 19	1975 Dec 15 (357)	197- 96 (260)	151	54	
1977 Jun 26-1978 Aug 05	1978 Jan 22 (36)	286-124 (199)	136	30	
1979 Jun 06-1980 Oct 22	1980 Feb 25 (70)	300-187 (248)	162	41	
1981 Jul 28-1983 Jan 01	1982 Mar 31 (105)	354-238 (245)	194	56	
1983 Aug 11-1985 Mar 29	1984 May 11 (145)	21-331 (311)	218	59	
1985 Sep 19-1987 Jun 22	1986 Jul 10 (202)	59- 38 (340)	240	90	
1987 Nov 09-1989 Jun 12	1988 Sep 28 (280)	100- 53 (314)	261	306	
1990 Jan 25-1991 Sep 20	1990 Nov 27 (340)	157-117 (321)	199	97	
1992 Apr 24-1993 Nov 14	1993 Jan 07 (22)	236-166 (291)	152	74	
1994 Mar 19-1995 Aug 01	1995 Feb 12 (58)	241-134 (254)	130	66	
			Total	1100	2

			Average	106
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RARELY OBSERVED CLOUD BANDS

Rarely observed are the Planetary System Cloud Banding or Equatorial Cloud Band (ECB) ECBs are broad and diffuse hazy streaks usually observed crossing within ± 20 degrees of the Martian equator. Cloud bands are detected visually using a deep blue (W47B) or violet (W47) filter or photograph ultraviolet or violet light. Cloud bands are probably composed of thin CO₂ ice crystals carried aloft by altitude winds.

Until recently, cloud bands were most often observed during the Martian northern summer, however systematic tricolor CCD imaging has uncovered evidence these wisps of cloud bands may be more frequent and may occur in all Martian seasons. Using a special Infrared blocking filter in conjunction with high glass Wratten red, green, and blue filters these ECBs are readily detected and may be unseen by observers.

The I.M.P. has initiated an observing program for intensive investigation into these phenomena and will notify all planetary observers using CCD technology to assist us in this important study.

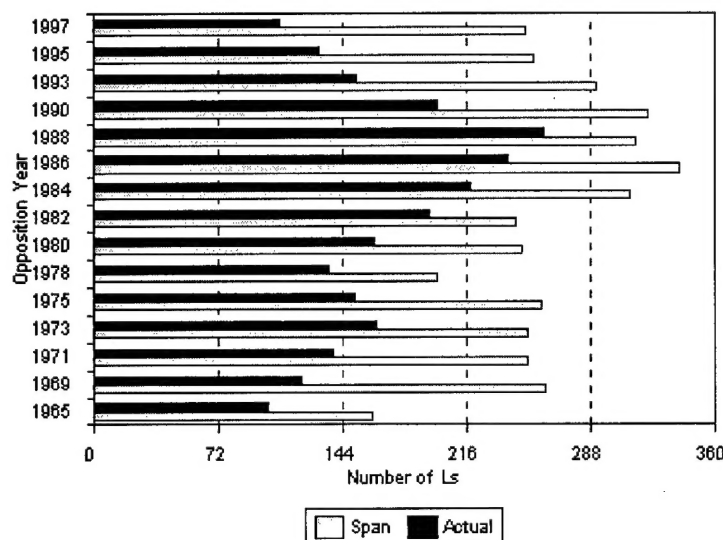


Figure 1. Graph of observational coverage during Mars apparitions as indicated by the corresponding opposition year. Graph includes number of degrees Ls span for last observation and number of degrees Ls covered by actual observational reports.

ANALYSIS METHODS

Each of the 24,130 Mars drawings, photographs, CCD images in the ALPO Mars Section Observing Report Library was carefully evaluated for quality and accuracy, with special attention given to proper color filters. When multiple observations of a particular phenomena was evident, its precise size, shape, location was computed using the least squares method. To reduce systematic errors, the "personal equation" for each participating observer was derived from this computation and used to quantify their experience.

Systematic errors are also found in our data as a result of the nature of the reporting of Mars observations. One might think of these observations as discrete samples of time or "snap shots" of the conditions on Mars. Due to the fact we cannot possibly record every moment of Mars' history, even with the excellent long-term coverage provided to us by our world wide network of observers. Large gaps in areographic longitude remain unseen. To identify

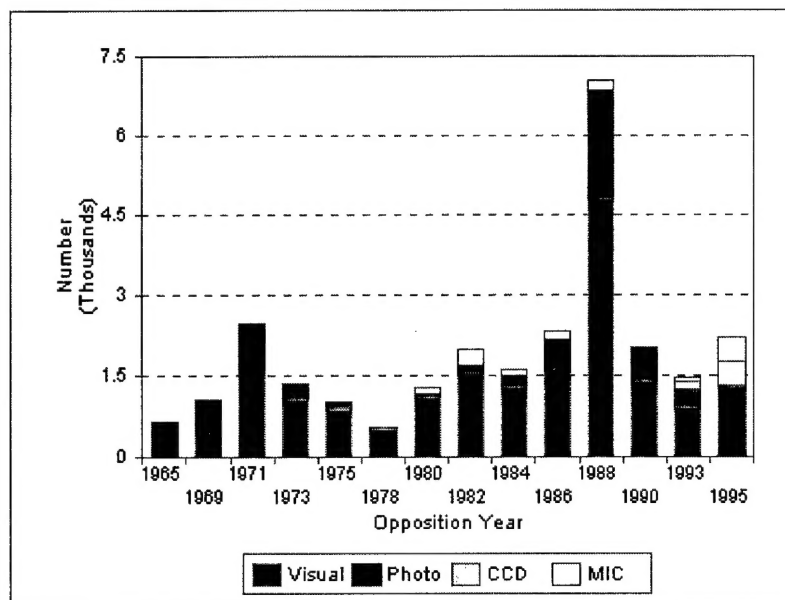


Figure 2. Bar graph showing number of observations by type, i.e., visual drawing reports, photographs, micrometer measurements, and CCD images.

simultaneous observations of clouds or white areas seen by several astronomers is much less difficult than observations of separate limb phenomena. This is because limb hazes and clouds appear to stick close to the limbs and phenomena rotate with the planet, as if these clouds are continuously being created and destroyed.

In performing this study we have made every effort to reduce systematic errors. The least square method was employed to construct each individual observer's personal error equation. Each observer's experience, reliability, type and size telescope used, reported atmospheric "seeing" conditions, and general location were considered carefully when selecting observations for the survey.

Whenever available, photographs were utilized to cross check and confirm phenomena reported visually. Nevertheless, owing to the orbital geometry of Earth and Mars and Mars' axial tilt, considerable observation is unavoidable. For example, the sub-earth point (De) can be situated more than 25° from Mars' equator for an apparition. This prohibits observations of those regions near the hidden pole. Areas from latitudes 90° and more are sometimes hidden as are the back side of Mars and terminator areas. All these lost observations go into the "bucket of the unknown." Other sources of bias include the greatly varying distance of Mars from Earth (changing Mars' apparent size by some 4-5 times), the period near conjunction with the Sun, when Mars cannot be observed at all or only briefly each night, and the changing value and position of the phase angle which complicates observations of hazes and clouds near Mars' poles, limbs, and terminator. These problems are all but uncontrollable, since we cannot yet change our vantage point and must remain earthbound.

STATISTICAL ANALYSIS

Statistical analysis was carried out using a 486DX2-50 Express Business Computer and Gateway-2000 66 Business Computer. Graphics plots presented here have been the product of Borland's Quattro Pro 5.0.

The tables in this report are simple percentages of the frequency with which we observe the various meteorological phenomena on Mars. Owing to a small difference in axial tilt, Mars' seasonal periods are similar to those of Earth. When observing Mars from Earth, we see both the planet's northern and southern hemispheres, so we must specify that hemisphere's season and it is indicated on each graph and table.

Due to the longer year and higher eccentricity of the Martian orbit, the seasons on Mars are not as symmetrical as Earth's. The Martian northern spring and summer are longer than autumn and winter, (reversed Southern Hemisphere).

For statistical analyses, percentages are generally based on the number of activities of weather phenomena observed during seasonal periods versus the actual time spent observing Mars during that particular period. The Martian year of four seasons starts with its vernal equinox at 0° planetocentric longitude (Ls) and proceeds eastward in its orbit through the seasons. Martian seasons are defined as: spring (0° - 89° Ls), summer (90° - 179° Ls), autumn (180° - 269° Ls), and winter (270° - 359° Ls). For this study, the Martian year is subdivided into 90° periods, measured in degrees of Areocentric or planetocentric longitude of the Sun (Ls); and the abbreviations "Nsp/Sau," "Nsu/Wwi," "Nau/Wsp," and "Nwi/Ssp" correspond respectively to "spring," "summer," "autumn," and "winter" that identifies with the Martian seasons in each of the planet's hemispheres.

To provide a valid and systematic distribution of the observational data, I chose to (1) discard observations made when Mars was less than 6 arcsec apparent diameter, (2) exclude seasonal periods with less than 12% observational coverage, and (3) eliminate observations by very inexperienced or novice planetary astronomers. These three criteria confine analysis to at least much of each Martian season occurring immediately before and after opposition and to observations made by experienced planetary astronomers.

Table II and III summarize the results of our statistical analysis for each phenomenon by season. Although our knowledge of "white areas" is limited, their characteristics suggest they are surface deposits of frosts. I included white areas in this survey because these phenomena may prove to be both surface and atmospheric in nature. Also, bright areas have been observed immediately after dust storm activity further suggesting deposits of fresh dust.

Figure 3 represents a more detailed breakdown for each type of meteorology by season and includes the southern hemisphere occurrences as well. In each case, the percentages reflect the number of activities versus the number of degrees Ls observed for each period.

RESULTS

One striking finding of this study is the marked proclivity for limb clouds and discrete clouds to appear in the northern hemisphere spring and summer. This seasonal preference may result from different compositions of the polar caps. Viking data has shown that many of the white limb and discrete clouds are composed of ice crystals. The Viking spacecraft have demonstrated that the primary composition of the South Polar Cap (SPC) is carbon dioxide ice (CO₂) with perhaps a tiny core of water ice clathrate [James *et al.*, 1979]. The North Cap consists of a layer of carbon dioxide covering a fairly large water-ice remnant [Kieffer, 1976]. The frequency distribution of these clouds appears to follow the regression of the north cap, in that as the remnant cap is exposed during Martian northern summer.

The much lower incidence of white clouds during southern spring and summer agrees well with Mars' asymmetry in water vapor abundance [Farmer and Doms, 1979; Jakosky and Farmer, 1982]. It should

be pointed out, however, that the apparitions most favorable for studying these Martian seasons were in 1973, years of global dust storm activity. During these two apparitions, dust clouds obscured large areas

planet throughout much of the southern spring and summer, reducing the chances of observing white clouds. While this has no doubt introduced some bias, our preliminary reduction of the considerable data from 1986 and 1988 apparitions [Parker et al., 1989] suggests that there is indeed much less discrete and limited activity in southern spring and summer than there is during these seasons in the north. Even the orographic clouds in 1986 around 200°-220° Ls were neither so numerous nor so long-lived that they would be expected to alter the dominance of the "more usual" northern spring/summer meteorology in this survey. The 1986 apparition displayed even fewer clouds, despite a record number of experienced observers participating in the meteorological survey. As the data from 1986, 1988, 1990, and 1993 is added to this study, any bias in the global storms has been reduced considerably.

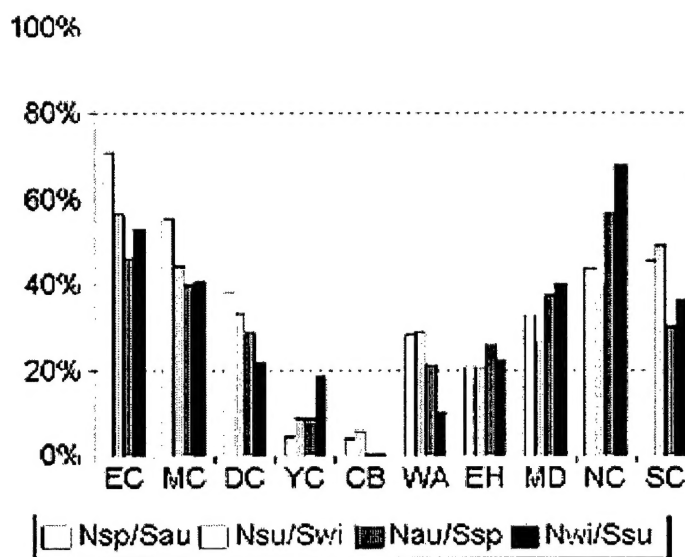


Figure 3. Graph indicating the overall simple average meteorological active degrees Ls during all apparitions from 1964 through 1993. Each type of meteorology in the vertical scale and percentage of the observed Martian year is indicated in the horizontal axis. The terms Nsp/Sau = Northern spring/Southern autumn, Nsu/Swi = Northern winter, Nau/Ssp = N. autumn/S. spring, and Nwi/Ssu = N. winter/S. summer.

A short-term climatic phase of this survey is being completed. Although the seasonal coverage is incomplete for 1971 and 1973 (due to global dust storms) enough data was available to qualify the survey under the 12% criterion. I have also included data from C.F. Capen's observational records and photographic library from the 1964-65 and 1966-67 apparitions and further reducing the data from the 1962-63 apparition observations and photographs by C.F. Capen.

Despite the resultant gaps in the coverage, meteorological observations of the 1960s are considered credible since C.F. Capen, who organized this survey, performed most of the work at Table Mountain Observatory.

As a result of this survey this author will not rule out the possibility of short-term and highly variable changes on Mars as predicted by past I.M.P. studies and has published these suggestions before [Parker 1983]. On the surface this meteorology study can be used in conjunction with past studies of the Martian cap behavior indicates the planet Mars was either cooler during the 1960's and warmer in the early 1970's. The observing techniques and equipment have so biased our results that we need to completely revolutionize the art of observing the Solar System with more objective methods.

The spacecraft missions to Mars during the 1960's and 1970's have resulted in a new impetuous for g based telescopic observing of the Red Planet. Astronomers are now armed with new knowledge about made available by close-up surveillance by the Viking Orbiters and Landers. Of course, the loss of Observer has ended prospects of continuing the close-up watch on Mars and all those machines are just junk now.

The benefits of the study of Mars' climate will help in the understanding of our own planet's climate methods arrived from the meteorological survey of Mars using A.L.P.O. observations and modern tech will increase our knowledge of the planet Mars. The amateur astronomer has earned a place in modern s

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